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AFFORDABLE TACTICAL LOW ALTITUDE SATELLITE TECHNOLOGY TASK

QUALCOMM Inc.

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AFFORDABLE TACTICAL LOW ALTITUDE SATELLITE TECHNOLOGY TASK

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13. ABSTRACT (Maximum 200 words)
The Affordable Tactical Low Altitude Satellite Technology (ATLAST) program focuses on developing an architecture for a system providing tactical and beyond line-of-sight communications employing a constellation of satellites in Low Earth Orbit (LEO). A LEO based approach may result in a cost effective system providing voice and data communications between small, low-power, mobile terminals and hub stations. A constellation of small, inexpensive, lightweight satellites can be launched into LEO at a cost lower than that for higher orbits. Also, using LEO assets requires much less power to close the link. This report presents the approach to designing such a system and summarizes the design. The initial communications requirements are presented, and the impact discussed. Trade-off involving geometries for tactical links are presented. The baseline strawman design is given, including communications link budgets.

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1 INTRODUCTION

The Affordable Tactical Low Altitude Satellite Technology (ATLAST) Task resulted from the re-direction of the Adaptive Receive Node Scheduling (ARNS) Program on 03 Jan 1989. The ATLAST Task focuses on developing an architecture for a system providing tactical and beyond-line-of-sight communications employing a constellation of satellites in Low Earth Orbit (LEO). This Final Report covers only the effort expended on the ATLAST Task.

An LEO-based approach may result in a cost-effective system providing voice and data communications between small, low-power, mobile terminals and hub stations. A constellation of small, lightweight, inexpensive satellites can be launched into LEO at a cost lower than that for medium Earth or geosyncronous orbit. Also, using LEO assets requires much less power at the terminal to close the link since path loss is proportional to distance squared.

This final report presents QUALCOMM's approach to the development of an LEO-based tactical communications system, and summarizes the design of such a system. The report begins with a description of the desired system. The set of initial requirements for the communications system is then presented, and the impacts discussed. The report continues with some trade studies involving geometries of tactical communications, and conclusions. The baseline strawman design is then presented, complete with the communications link budgets. The report ends with a discussion of possible enhancements to the system, and other areas of research.

2 TACTICAL COMMUNICATIONS SYSTEM DESCRIPTION

The communications need being addressed in this report is of a tactical nature. The system must provide beyond line-of-sight communications for a theater of some maximum size. The intra-theater communications consists of voice and data at varying data rates. Because of the voice data, there is a maximum latency within which the system must perform. The communications must exhibit some Anti-Jam (AJ) capabilities, though this is not a driver of the system. There is also a desire for the waveform to exhibit Low Probability of Intercept (LPI) in order to protect certain segments of the communications system.

The ground segment of the communications network includes a variety of possible terminals including:

small, low-power, transportable and mobile terminals supporting low data rates;

higher-power transportable terminals capable of supporting higher data rates;

high-power,fixed ground stations with large-gain antennas that operate as hubs and relays for the network.

The space segment of the tactical communications network consists of small, lightweight, inexpensive satellites launched into LEO. The satellites are designed to be launched in groups, so as to reduce the number of launches per orbital plane. The satellites may possess crosslinking capabilities. Depending on the reduction of the total number of assets, or the enhancements, that such a crosslinking capability affords to the network, the satellites might communicate to a few or many neighboring satellites.

3 BASELINE REQUIREMENTS

The initial requirements from which the system design of the tactical communications network is derived are included below. The requirements are first listed, then are grouped in such a manner as to facilitate the ensuing discussion as to their relationship to the various network issues and design.

The following comprise the initial set of requirements for a tactical LEO-based satellite communications network:

- Theater size: 250 mi radius.
- One base camp per theater (there may be many theaters).
- Multiple simultaneous "operations" per theater.
- 24 hour coverage.
- 4 voice channels for intra-theater communications, mostly comm to/from base camp.
- One voice channel from base camp to/from CONUS.
- One high-speed (56 Kbps) data channel for base camp to/from CONUS.
- LPI for operations, not needed for base camp.
- Operations' mobile terminal should be small, easy to operate, quick to initiate comm, etc.
- Base camp equipment must have battery powered option.
- May need occasional voice communications between ops to/from CONUS.
- Possibility of doing position location of a person.

A brief discussion of the impacts of the initial requirements follows. The arrangement and grouping of the requirements allows for discussion of the pertinent impacts to the system design.

- Theater size of 250 mile radius; 24 hour continuous coverage; one base camp (hub) per theater.

The theater size dictates the dwell of that theater in the footprint of a LEO satellite. The fact that there exists a hub station in each theater, that the communications coverage of the theater must be 24-hour, together with the theater size dictates the number of LEO satellites necessary. Though the actual altitude of an LEO satellite could vary from ~250 nm up to 500 nm, the experience with the Multiple Satellite System (MSS) program and launch vehicle suppliers has lead to a baseline altitude

of 400 nmi. This altitude is useful in defining the direction and capabilities of the LEO system, but should not be perceived as a fixed parameter.

At an altitude of 400 nmi, a satellite's footprint is approximately 1250 miles in radius assuming a 10° elevation angle for terminals. This translates to a requirement of 10 to 14 satellites per orbital plane for continuous coverage of a theater, depending on the crosslinking capability each satellite possesses. The theater dwells inside a single satellite's footprint up to a maximum of 10 minutes. The number of satellites required by the network to achieve continuous coverage versus crosslinking capability of the satellite's is discussed in detail in Chapter 4.

- Multiple simultaneous operations per theater; 4 voice channels for intra-theater communications.

The requirement of multiple simultaneous operations requires some sort of a multiple access scheme to be inherent in the system design. Though there are many choices for the type of multiple access scheme to be employed, QUALCOMM has chosen Code-Division Multiple Access (CDMA) as the baseline. As it turns out, CDMA makes extremely efficient use of a communication system's resources for voice communications. CDMA works by spreading each users signal over a wide instantaneous bandwidth at the transmitter, and then de-spreading at the receiver. The spreading makes all other users' signals to look like noise compared to a single user's. Because each user has its own code to do the spreading, the receiver can pick out the proper signal and reconstruct it.

What makes CDMA the optimum multiple access scheme for voice communications systems is the inherent voice duty cycle. While two users are talking to one another, on average each user talks 35% of the time for the duration of the conversation. This duty cycle may result in a substantial inefficiency in the use of the communications resources in systems employing Time-Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA). TDMA and FDMA systems cannot reallocate the resource because of the characteristics of the voice duty cycle (short duration, high frequency , and highly variable). But the CDMA system can because if the transmitter of a user is shut off each time the user becomes quiet, this translates directly to less noise to the other users. So an intelligently designed CDMA system may have a larger capacity than that of a system employing TDMA or FDMA.

Using CDMA in a non-synchronous manner will allow for 10's or 100's of simultaneous intra-theater voice channels. If only four channels are necessary, then a much simpler scheme with random access and no spread-spectrum would suffice. But four channels sounds like an extremely low bound, and a tactical system of this nature would probably need to support 10's to 100's of simultaneous users.

The choice of CDMA coupled with the desire to keep the cost of the space segment down has lead a system baseline in which non-processing satellites are used. The satellites are accessed by the employment of non-synchronous CDMA random access. This approach is simple, reduces acquisition and timing requirements, and maintains efficient use of network resources.

- 1 voice channel to/from theater to CONUS; 1 high-speed data channel to/from CONUS; 1 voice channel to/from ops to CONUS.

The requirement for communications to and from CONUS is difficult to fulfill by employing the LEO satellites alone. The goal of the MSS program was to provide global communications through a network of LEO satellites. To achieve this goal, the MSS network required large numbers of expensive satellites and the invention of an extremely complex and sophisticated link access protocol. QUALCOMM recommends a scheme in which the base station is equipped with a terminal to DSCS, or some other geosynchronous asset. The ATLAST LEO constellation will not be able to support a voice link to CONUS because there is no plan for complex crosslinks; if crosslinks exist, they are only required to go one hop to be useful for tactical communications.

- Small, lightweight, and simple to operate remote terminals; Base camp equipment more elaborate, but battery powered.

These requirements fit well with QUALCOMM's baseline approach. The ATLAST concept is centered around the use of a small, low-powered remote terminal. As will be discussed later, the remote terminals need only 1 Watt of transmission power at L-Band while employing omni antennas. The base station is higher power (25 W), with tracking antennas, or a phased-array multibeam antenna. The battery powered requirement presents no problem to the baseline system.

- Operations are LPI; Base camp does not need to be LPI.

As discussed earlier, the need for LPI at the remote terminals is a basic desire of a tactical communications network. LPI is another reason to employ CDMA, since the

spreading affords the remote users with some LPI. More LPI can be attained by spreading the transmitted signals further using Frequency Hopping (FH). Not only does FH on the front end of the satellites provide increased LPI and processing gain, it also prevents unauthorized use of the network assets. Further LPI is achieved by low transmit power, and directive transmissions. As discussed later, the baseline architecture includes very low transmit power of the remote terminals. Also, the 20 dBi receive antenna gain of the base station results in added LPI. More LPI can be achieved by increasing the spreading bandwidth of the terminals, by employing power control at the remotes to reduce transmit power further, and by using directive antennas at the remotes to reduce the energy radiated toward an enemy.

- Position location.

The position location idea is possible. Using a single satellite, the result is two possible locations equi-distant from the sub-space orbital arc of the satellite. The ambiguity may be resolved by another satellite, or other information. The position location idea is further discussed in Chapter 6.

4 LEO SATELLITES AND TACTICAL COMMUNICATIONS

The dynamics of a satellite in LEO and the resultant impacts on a tactical communications network based on such satellites must to understood before the system design can take place. The low altitude of orbit results in both a high relative velocity of the satellite with respect to the Earth, and a small communications footprint. These two results combine to yield a communications resource which is available to a given theater for a small period of time.

At 400 nm, the footprint of a LEO satellite is approximately 2000 km in radius. This assumes a 10° elevation angle at the ground terminals. The theater size is assumed to be 400 km. The satellite velocity is 7.5 km/s and the period of orbit is 99 minutes. The satellite is in a ground terminal's FOV for at most 10 minutes per orbit.

These numbers directly influence the number of satellites required to provide 24-hour coverage to a tactical theater, and indicate the frequency of handover necessary to provide continuous communications. The following two sections cover the impacts of these factors on the communications network.

4.1 SATELLITE FOOTPRINTS AND COVERAGE

The initial set of requirements for the ATLAST tactical communication system includes:

- Theater size: 250 mi radius.
- 24 hour coverage.

Using these two requirements, a trade study is conducted in order to compute the number of LEO satellites required to provide 24-hour coverage and the crosslink capabilities necessary of the satellite. The numbers derived below represent a lower bound to the number of satellites required, since the geometric relationships assumed here are produced by satellite which are not constrained to actual orbits. But it is believed that the relative results are valid; the actual number of satellites required scales upward proportionally in all cases.

There are three levels of crosslink capability feasible to employ on each LEO satellite:

A. No crosslink capability. This implies that at any given time, a theater must be *completely* contained within a satellite's footprint. This case requires that the footprint patterns exhibit a large overlap.

B. Intra-ring crosslink capability. A satellite has the capability of communicating to the next/previous satellite within its orbital plane. This crosslinking capability requires yaw stabilization and link acquisition and maintenance functionality, along with one or two special crosslink antennas. The footprint overlap requirement is reduced in this case over that of case A.

C. Inter-ring crosslink capability. This case represents an MSS-like crosslinking capability, and the requirement for a complex type of link access protocol, not to mention a special purpose phased-array antenna. This case requires a minimum of overlap of footprint's of the satellites.

Figures 4.1 through 4.3 illustrate the footprint overlapping patterns required for each of the above-mentioned cases. These patterns are constructed using a 400 nm altitude and a 250 mi theater radius. This translates to a satellite footprint with radius 2000 km, and a tactical theater of 400 km radius. The large radius circles represent the satellite footprint; the small radius circle is the theater.

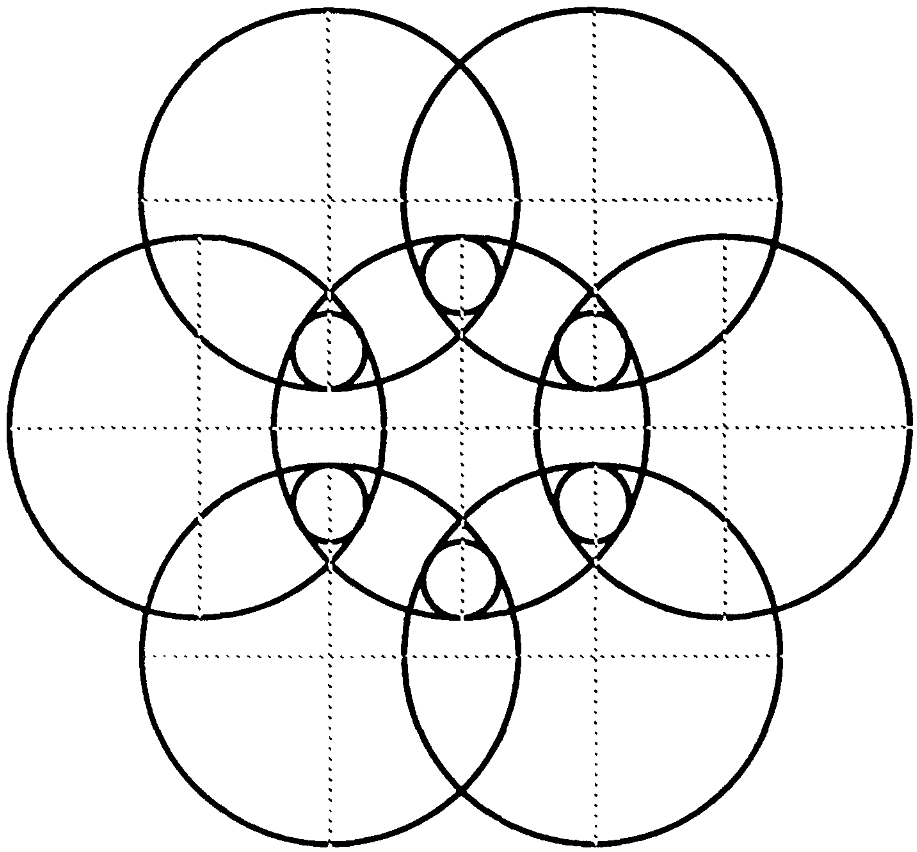

Figure 4.1. Footprint Patterns of Coverage for Case A.

In case A, the satellite footprints must overlap to such an extent as to insure that a theater is always covered completely by a single footprint. As shown in Figure 4.1, this is accomplished by spacing the centers of each footprint such that the intersection of three neighboring satellites covers the desired theater-sized area.

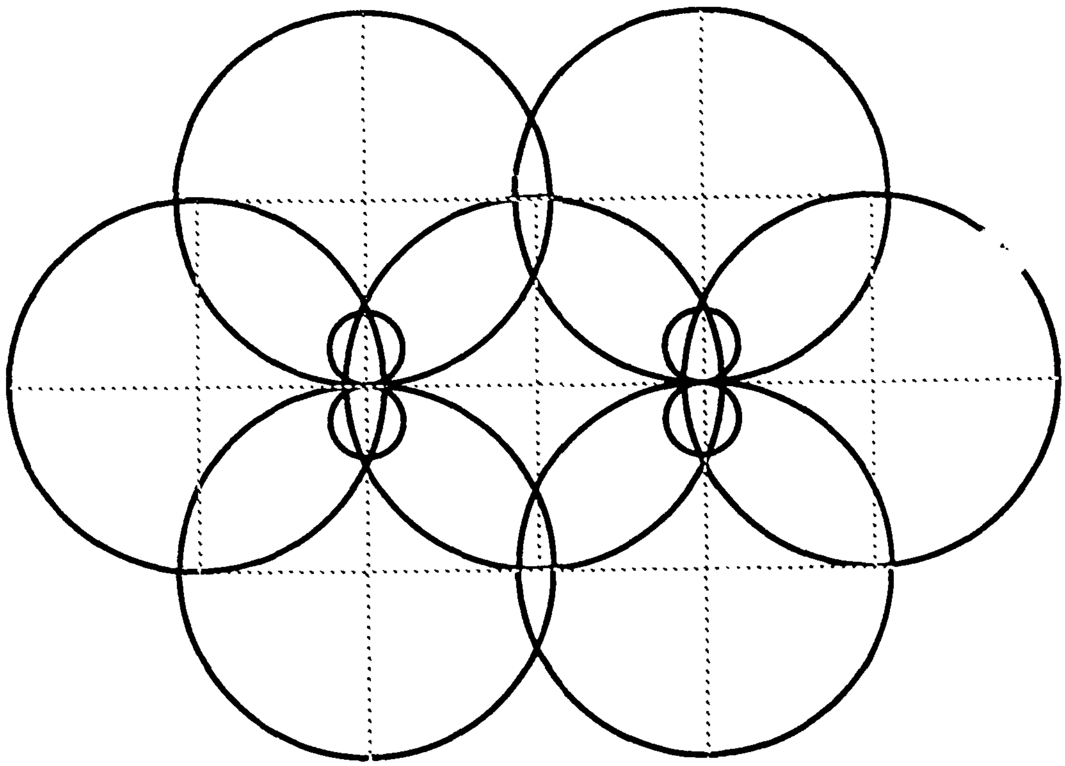

Figure 4.2. Footprint Patterns of Coverage for Case B.

Case B allows for the overlap area to be decreased. Figure 4.2 illustrates this fact, showing that the theater is covered entirely by one satellite, or by two horizontally neighboring satellites. If the theater is covered by two such satellites, users in one half of the theater can communicate with users in the other half through the crosslink performed by the two neighboring satellites.

The footprint pattern for case C satellites is presented in Figure 4.3. This case represents a situation in which a satellite can crosslink to any of its neighboring satellites. The relative size of the theater to be covered does not influence the spacing of the footprints, since this case is driven solely by the desire to minimize the overlap of the footprints.

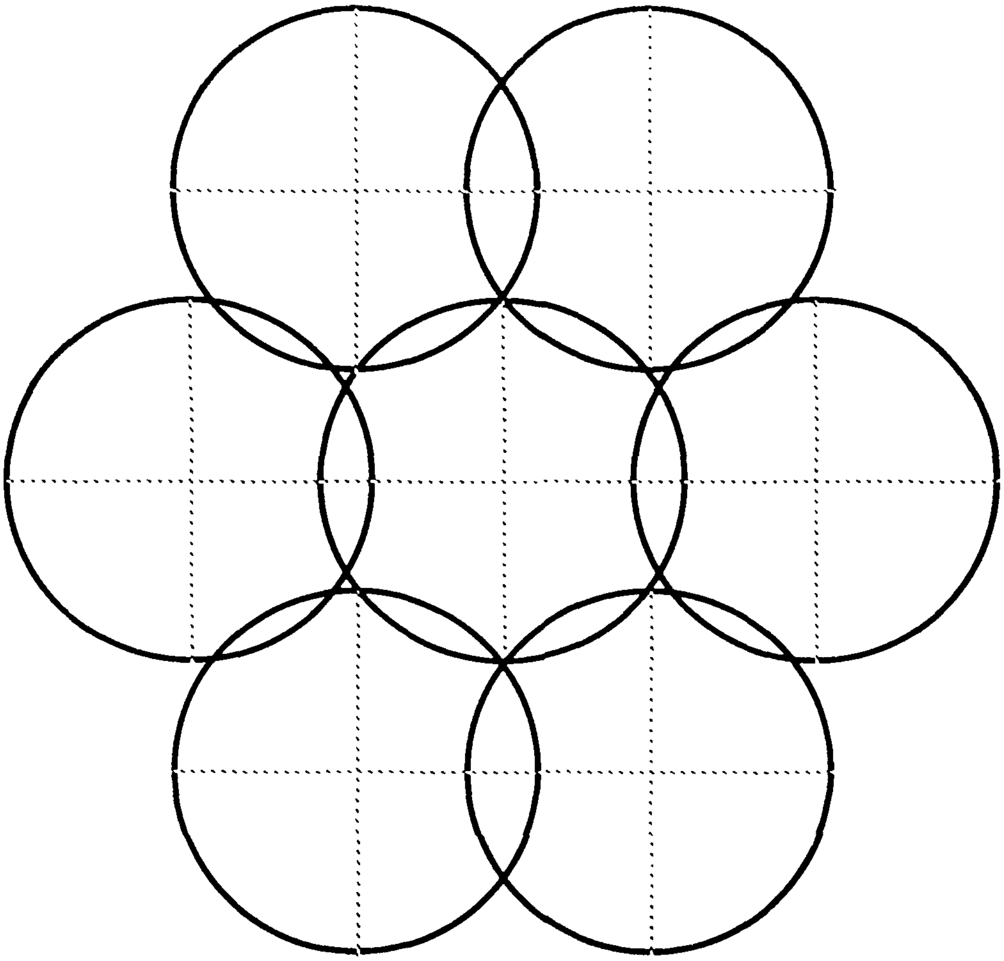

Figure 4.3. Footprint Patterns of Coverage for Case C.

Based on these coverage patterns, it is possible to calculate the number of satellites required to provide 24-hour coverage to in each case. Figure 4.4 is a chart illustrating the number of satellites required to achieve continuous coverage versus satellite altitude for each crosslink capabilities case. This chart assumes a theater size of 400 km. The chart also includes a theoretical lower limit for the number of satellites in which the footprint patterns are not circular in nature. This limit is not a practical one, but provides a point of reference for the other graphs.

Figure 4.4 indicates that cases B and C provide only a small reduction in the number of satellites necessary over case A. For instance, at an altitude of 400 nm, 88 satellites are required in case A, 77 in case B and 55 in case C. The reduction in the number of satellites required to provide continuous coverage when satellites possess inter-ring crosslinking capabilities is 38%. When satellites only crosslink within an orbital ring, the reduction is 13%. Considering the small reduction in satellites afforded

compared with the complexity and cost associated with providing crosslinking capabilities, these results lead to a network of non-crosslinking satellites.

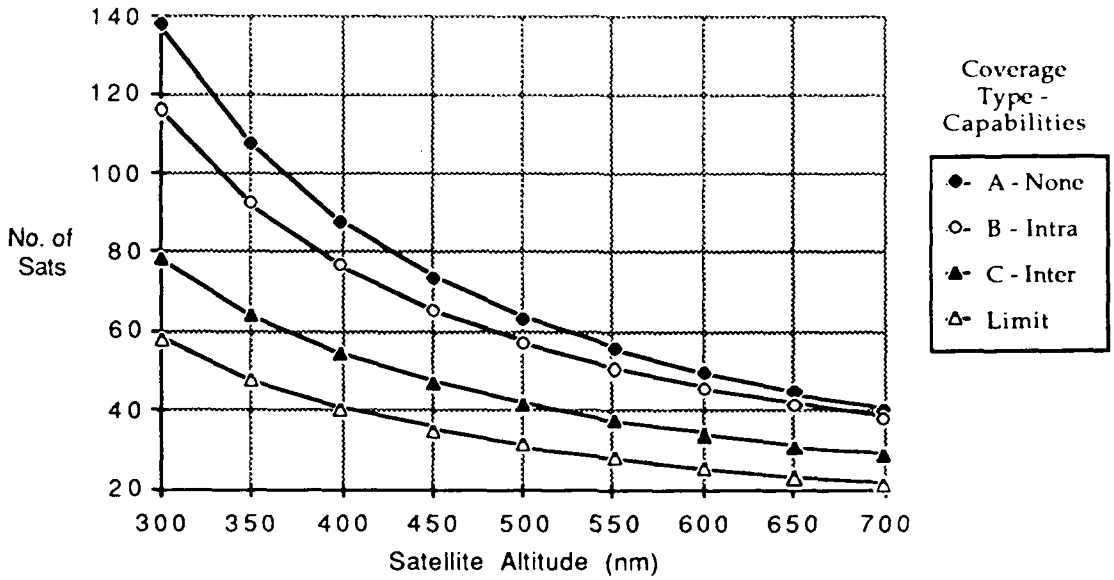

Figure 4.4. Number of Satellites Required vs. Altitude.

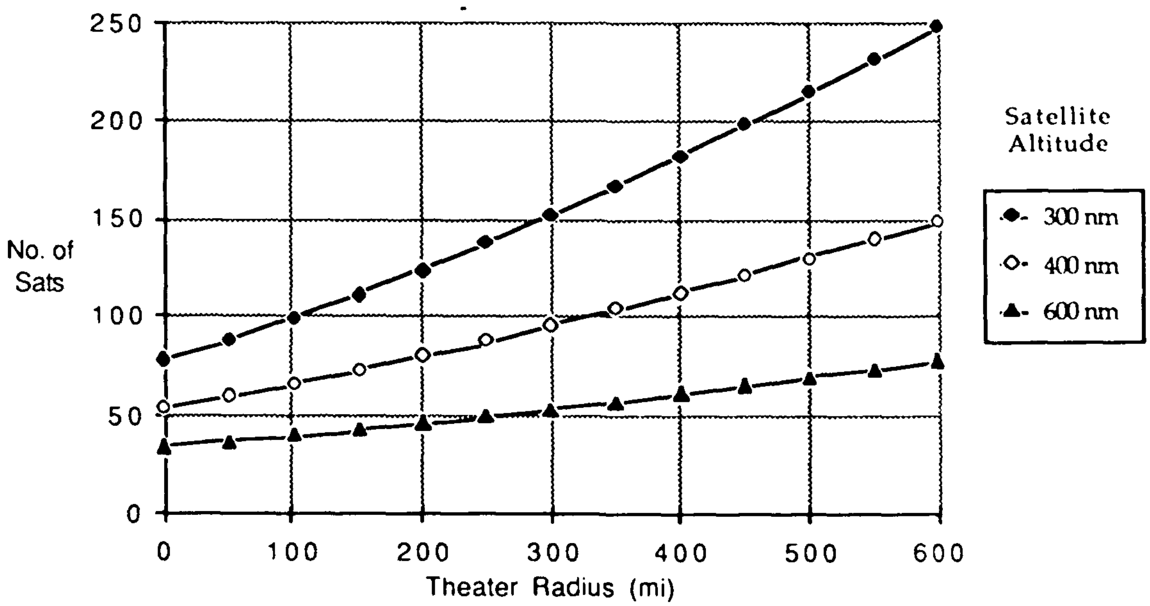

Figure 4.5. Number of Satellites Required vs. Theater Size.

Figure 4.5 is included to provide a feel for the sensitivity of coverage A type patterns to the theater size. For a 400 nm altitude satellite, the number of satellites required varies from 80 to 100 as the theater size increase from 200 to 300 mi (320 to 480 km).

4.2 DWELL IN AN LEO FOOTPRINT

The other technical trade study involves the dwell of a theater in a satellite's footprint. The relatively short duration of the dwell of a hub station and a remote terminal in a single LEO satellite's footprint requires frequent handover from one satellite to another. The average frequency of handover from one satellite to another is determined by the duration of the dwell.

The dwell is related to the geometry of the theater to the sub-satellite arc and of the hub to remote terminal. Figure 4.6 illustrates the geometry of interest in determining dwell times. The duration of the dwell is a function of the distance from the hub station to the sub-satellite arc, the distance from hub to remote, and the angle from hub to remote.

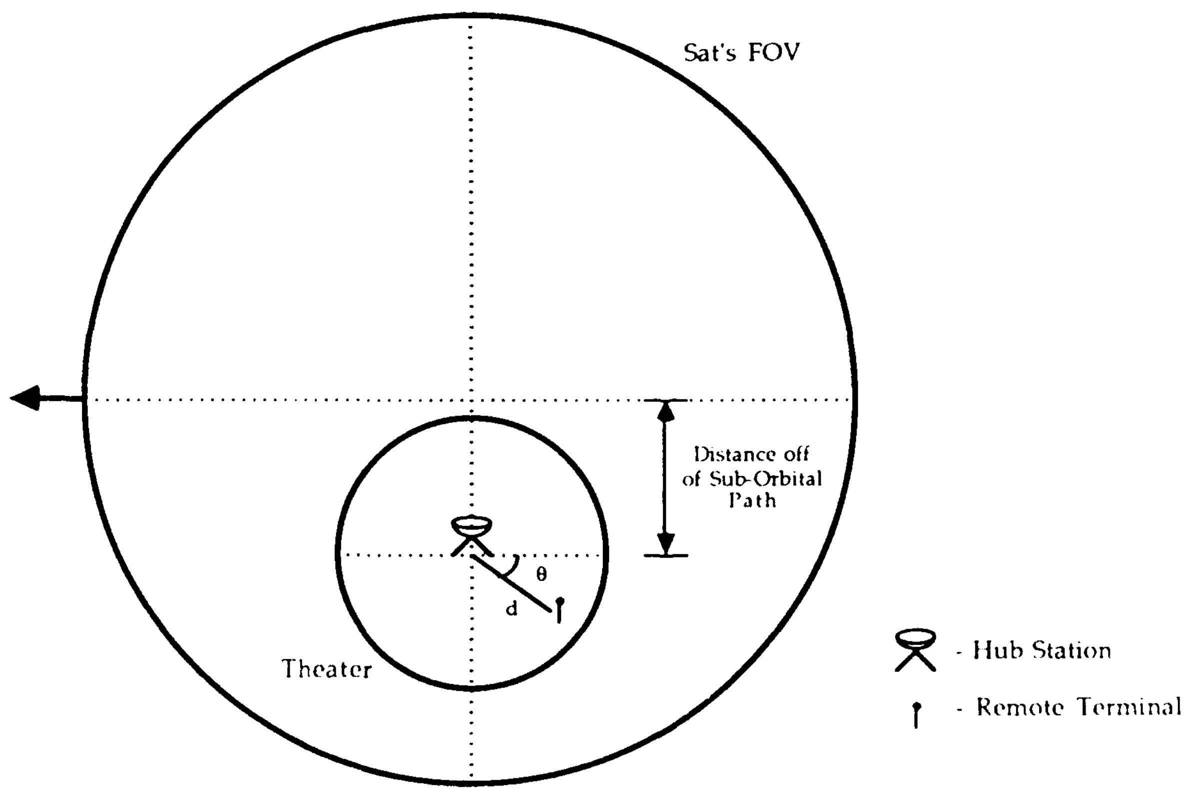

Figure 4.6. Geometry of the Dwell in an LEO's Footprint.

The following two figures depict the reduction in the duration of the dwell as a function of hub-remote distance and angle for a satellite at 400 nm, and elevation angles of 10°. Figure 4.7 illustrates the reduction from the maximum dwell of 10.0 minutes for the case when the hub sits on the sub-satellite arc. Figure 4.8 illustrates the reduction when the hub is located 1500 km off of the sub-satellite arc.

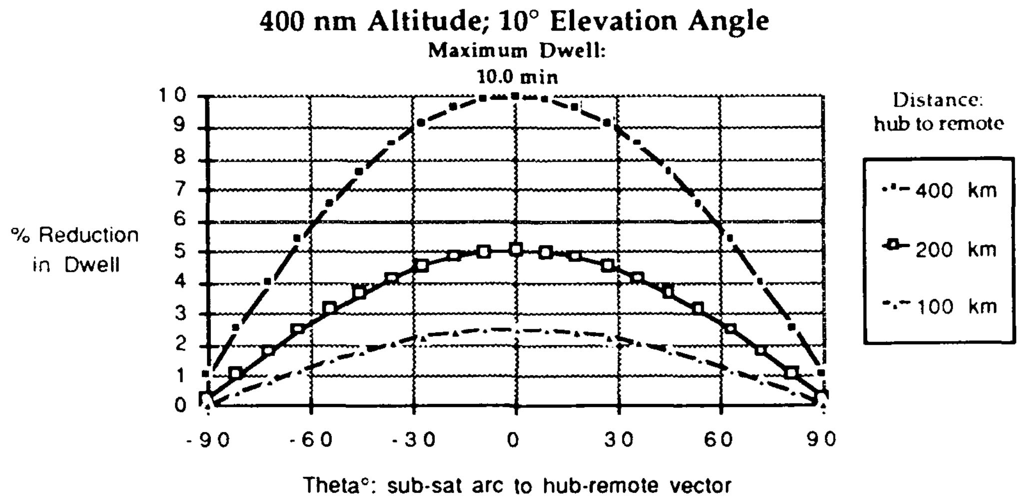

Figure 4.7. Dwell Reduction on Sub-Satellite Arc.

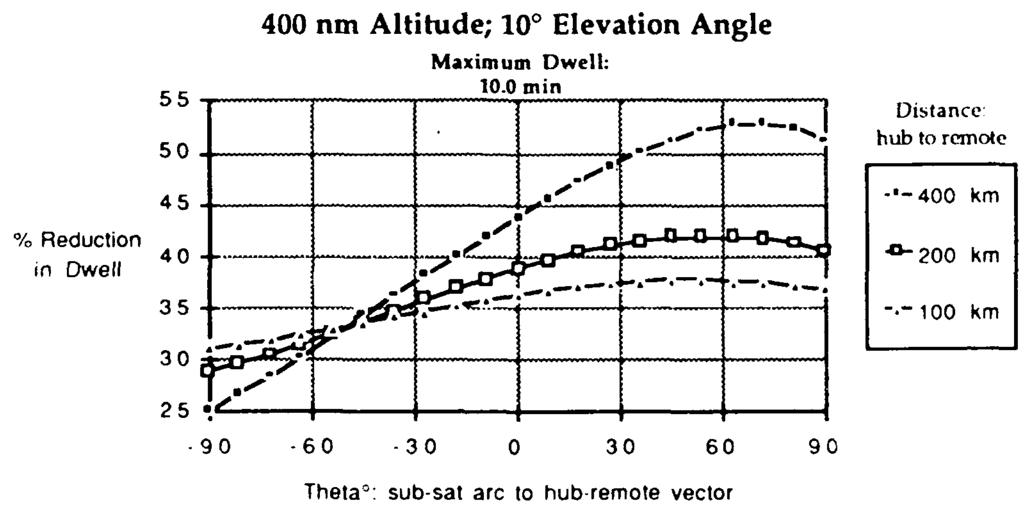

Figure 4.8. Dwell Reduction 1500 km off of Sub-Satellite Arc.

Because of the coverage selected from the first study, the average worst case dwell is limited, while the average dwell is characterized approximately by the case when the hub is located 800 km off of the sub-satellite arc. In this case, the dwell varies from 8 to 10 minutes. But the overlapping coverage proposed in case A does create a need to switch between three satellites quickly.

5 STRAWMAN ARCHITECTURE

The strawman architecture of the ATLAST communications network is presented in this chapter. The waveform parameters and link information is first explained. The access scheme and system design description follows. Then each of the elements of the network (satellite, remote terminal, and hub station) is specified. The strawman architecture concludes with a discussion of link margins, and the link budget.

5.1 WAVEFORM

The following represents the baseline waveform design and related parameters for the ATLAST communications network:

- Communications performed at L-Band (1.4 MHz).
- CDMA spreading over a bandwidth of 5 MHz.
- Vocoder data rate of 4.8 Kbps.
- Link designed for 1e-3 BER (2.5 dB margin for r=1/2, k=7 Viterbi decoding).
- Frequency hopping at transponder front-end.

Using L-Band for the RF frequency has the advantage of little interference from other users. There are not that many operational communications systems at L-Band. Also, the effect of atmospheric conditions on communications at this frequency is minimal. Power is relatively cheap to upconvert at L-Band versus higher frequencies so that the size and weight of remotes terminals is kept down. Finally, L-Band allows for use of an omni-directional antenna at remotes with less path loss than that at higher frequencies.

The use of CDMA provides advantages to a voice communications system over other waveform designs and multiple access schemes. The spreading of the voice data provides the remotes with some LPI, and some processing gain over a jammer (10 KHz over 5 MHz => processing gain of 27 dB). With voice-activated terminal equipment, CDMA becomes very efficient for multi-access voice communications because of the low duty cycle inherent in voice. CDMA also helps limit the interference which the ATLAST network imposes on other networks and users.

The vocoder rate of 4.8 Kbps is a standard that provides high enough quality voice to be able to discern the identity of the talker. The 1e-3 Bit Error Rate (BER) specified is the normal operating BER for voice communications system designs. Employing a convolutional code of rate 1/2 and a Viterbi decoder at the receiver with constraint length k=7 requires a 2.5 dB Eb/No margin. The margin is discussed in more detail later.

The strawman architecture includes a waveform that is frequency hopped along with the direct spreading. Frequency hopping protects the transponders of the satellites from unauthorized access and capture. A hopping rate of 10 Khps would afford maximum security and anti-jam protection for the rate 1/2 vocoded data. The hopping does adds complexity to the system and the acquisition process, so that the exact hop rate must be traded against simplicity of modem and desired speed of acquisition.

5.2 SYSTEM DESIGN

The strawman architecture employs a random access, non-synchronous CDMA access scheme. This is a simple process which minimizes initialization and synchronization requirements. The satellite or hub sends out a CDMA pilot signal using a known short PN sequence. This pilot speeds acquisition and helps in tracking and maintaining of the communications link.

The modem employs convolutional encoding and Viterbi soft-decision decoding, and the data is interleaved to provide robustness against multipath fading, and jamming, both intentional and unintentional.

The strawman architecture also includes power control of the remote terminals. Closed loop power control is achieved through the feedback of transmit power adjustment information to each remote. Open loop techniques are also employed at the remote by sensing the received power level from the hub, and calculating the link quality and signal environment. Open loop operation depends on an assumption of symmetry with respect to the communications links and therefore may not be appropriate in certain scenarios.

Controlling the transmit power of the remotes is useful for a number of reasons. The lowered average transmit power provides additional LPI. The transmitter uses just enough power to complete the link and thus does not radiate any additional

energy. The lower power of each transmission also results in less interference for other users. In the ATLAST CDMA environment, less interference results in the ability to support more simultaneous users. Finally, power control means less average power needed by the remote so that the required power subsystem, the major weight contributor to the terminal, is reduced.

The ATLAST communications system employing the multiple access scheme with CDMA pilots and power control can easily support 200 simultaneous users. This conclusion is further substantiated in the Link Budgets section.

5.3 NETWORK ELEMENTS

The presentation of the strawman architecture continues with a brief description of each of the segments of the ATLAST network. The LEO satellite design is discussed first, followed by the remote terminal, and then the hub station.

5.3.1 Satellites

The LEO satellites of the ATLAST network are lightweight, single bent-pipe transponders. The satellites are non-processing with 20 W transmit power and 5 dBi of antenna gain. Considering the present satellite technology and a 20 W transmit capability, the estimated weight of each satellite is 100 lbs. The transmit power number is the amount necessary to complete the up and down links with the desired margin. The antenna gain is that for a downlooking transponder at LEO.

The launch vehicle of choice is the Pegasus space booster. Four such satellites can be put into a 400 nm orbit per Pegasus launch. The satellites are placed into several orbital planes, 6 - 12 per plane. The satellites possess station-keeping capabilities so that they maintain their relationships with respect to one another. The station-keeping capability is realized from each satellite's booster rockets, and in some sense comes for free.

The satellites are non-crosslinking. Section 4.1 presented evidence which stated that the cost and added complexity of crosslinking capabilities on the satellites is greater than the reduction in the number of total satellites necessary for 24-hour coverage. The conclusion favors non-crosslinking satellites. Because of the lack of crosslinking, the satellites need only be stabilized such that they point toward Earth. A simple, inexpensive device such as a gravity gradient boom is sufficient for the stabilization required. There is no need for yaw stabilization.

5.3.2 Remote Terminals

The remote terminals are man-transportable, low-power, and lightweight. The terminal may be half-duplex or full-duplex, depending on the application. The terminal is capable of mobile operation. The transmit power of the terminal is 1 W at L-Band with a 5 dBi gain omni-directional antenna.

5.3.3 Hub Stations

The hub station functions as the Earth-based relay for the tactical communications network. All remote-to-remote communications are routed through the hub. The large antenna gain and transmit power associated with the hub allow the remote terminals to be small and low-power. The hub also includes a gateway into terrestrial and/or other satellite networks in order to achieve communications with CONUS.

The hub station possesses a high gain antenna capable of tracking the LEO satellites. To prevent outages, the hub must have either two mechanically steerable dishes, or one phased-array multi-beam antenna. The proposed hub station has 25 W transmit power and 20 dBi of antenna gain.

5.4 LINK BUDGETS

The following tables represent the link budgets for the ATLAST network. Table 5.1 presents the hub-to-remote link, while Table 5.2 presents the remote-to-hub link.

For the baseline system of:

> L-Band (1.4 GHz down, 1.44 GHz up), 5 Mhz Spreading bandwidth, 4.8 Kbps vocoders, 1e-3 BER;
>
> Hub - 25 W transmit power, 20 dBi Tx antenna gain, -4.7 dB G/T;
>
> Remote - 1 W tx power, 5 dBi antenna, -21.0 dB G/T;
>
> Satellite - 20 W tx power, 5 dBi antenna, -22.0 dB G/T;

a margin of 2.8 dB for the Hub-to-Remote Link, and 4.5 dB for the Remote-to-Hub Link is realized.

Up:	Tx Power	25.0 W	14.0 dBW
	Feed Loss	0.63	-2.0 dB
	Hub Tx Antenna Gain	1.181 m	22.0 dB
	EIRP		34.0 dBW
	Number of Channels	200	-23.0 dB
	Voice Duty Cycle	35%	4.6 dB
	Path Loss (Slant Range)	2,243 km	-162.6 dB
	Data Rate	4,800 bps	-36.8 dB-Hz
	Sat. Gain	5 dBi	5.0 dB
	Sat. Temp	500 °K	-27.0
	–k (Boltzman's Constant)		228.6 dB-°K
	Uplink Eb/No		22.7 dB
	Transponder Bandwith	5 MHz	-67.0 dB-Hz
	Uplink Io		-190.6 dB-Hz
	Uplink Eb/Io		11.7 dB
	Uplink Eb/(Io+No)		**11.4 dB**
Flux:	Gain of 1 m^2 Antenna		24.6 dB/m^2
	Uplink Power Flux Density		-104.0 dBW/m^2
	Uplink Power Flux to Saturate Satellite		-100.0 dBW/m^2
	Input Backoff from Saturation		4.0 dB
	Compression at Saturation		5.5 dB
	Output Power Reduction from Saturation		**0.0 dB**
Down:	Satellite Tx Power	20.0 W	13.0 dBW
	Satellite Antenna Gain	5 dBi	5.0 dB
	Backoff Loss		0.0 dB
	Satellite EIRP		18.0 dBW
	Channels * Duty Cycle	70	-18.5 dB
	EIRP per Channel		-0.4 dB
	Path Loss	2,243 km	-162.4 dB
	Data Rate	4,800 bps	-36.8 dB/Hz
	Rx Ant. Gain	0.164 m	5.0 dB
	Eb		-194.6 dBW/Hz
	Ant. Temp.	300 °K	-203.8 dBW/Hz
	LNA Temp	100 °K	-208.6 dBW/Hz
	No	400 °K	-202.6 dBW/Hz
	Rx G/T		-21.0 dB/K
	Downlink Eb/No		**7.9 dB**
Total:	Combined Eb/No		6.3
	Implem. Loss		-1.0 dB
	Required Eb/No	1.0E-3 BER	-2.5 dB
	Margin		**2.8 dB**

Table 5.1. ATLAST Hub-to-Remote Link Budget.

Up:	Tx Power	1.0	W	0.0	dBW
	Feed Loss	0.89		-0.5	dB
	Hub Tx Antenna Gain	0.167	m	5.0	dB
	EIRP			4.5	dBW
	Path Loss (Slant Range)	2,243	km	-162.6	dB
	Data Rate	4,800	bps	-36.8	dB-Hz
	Sat. Gain	5	dBi	5.0	dB
	Sat. Temp	500	°K	-27.0	
	-k (Boltzman's Constant)			228.6	dB-°K
	Uplink Eb/No			11.7	dB
	Transponder Bandwith	5	MHz	-67.0	dB-Hz
	Number of Channels	200		23.0	dB
	Voice Duty Cycle	35%		-4.6	dB
	Uplink Io			-201.7	dB-Hz
	Uplink Eb/Io			11.7	dB
	Uplink Eb/(Io+No)			**8.7**	**dB**
Flux:	Gain of 1 m^2 Antenna			24.6	dB/m^2
	Uplink Power Flux Density			-133.5	dBW/m^2
	Uplink Power Flux to Saturate Satellite			-100.0	dBW/m^2
	Input Backoff from Saturation			33.5	dB
	Compression at Saturation			5.5	dB
	Output Power Reduction from Saturation			**28.0**	**dB**
Down:	Satellite Tx Power	20.0	W	13.0	dBW
	Satellite Antenna Gain	5	dBi	5.0	dB
	Backoff Loss			-28.0	dB
	Satellite EIRP			-10.0	dBW
	Path Loss	2,243	km	-162.4	dB
	Data Rate	4,800	bps	-36.8	dB-Hz
	Hub Rx Ant. Gain	1.158	m	22.0	dB
	Eb			-187.2	dBW/Hz
	Ant. Temp.	200	°K	-205.6	dBW/Hz
	LNA Temp	100	°K	-208.6	dBW/Hz
	No	300	°K	-203.8	dBW/Hz
	Rx G/T			-2.8	dB/K
	Downlink Eb/No			**16.6**	**dB**
Total:	Combined Eb/No			8.0	
	Implem. Loss			-1.0	dB
	Required Eb/No	1.0E-3	BER	-2.5	dB
	Margin			**4.5**	**dB**

Table 5.2. ATLAST Remote-to-Hub Link Budget.

6 CONCLUSIONS

This report presents a strawman architecture for a tactical communications network of LEO satellites. The emphasis of the design is on meeting the baseline requirements for tactical communications while producing a cost-effective network. QUALCOMM's approach incorporates advanced technologies in novel schemes to provide an elegant solution to the problem of inexpensive tactical and beyond line-of-sight communications.

There are several areas of interest that require further effort. The first area encompasses the availability of frequency allocations in L-Band. Clearly, a proposed communications network such as ATLAST must obtain an allocation in a frequency band before becoming a real possibility. If an exclusive band cannot to obtained in L-Band , sharing bands with other services at L-Band or UHF might be possible. The immediate issues which surface when UHF is considered are those relating to communications interference with other users and their interference with you, and the political impacts.

Another area of focus relating to the ATLAST network involves the possibility of calculating the position location of remote terminals based on the Doppler offset of their transmitted signals received at a satellite. A single satellite could estimate the location of a terminal based on processing the remote's transmission at two or three points along a satellites orbital arc. The accuracy of the estimate depends of the ability to calculate the Doppler offset of the transmission which in turn is dependent on the Eb/No, integration period, and noise environment (including noise figure at the satellite).

One last area of interest involves exploring the various antenna options at the remote terminal for increasing gain and providing LPI. The strawman architecture incorporates an omni-directional antenna at the remote with a gain of 5 dBi. By increasing the gain at the remote the required transmit power is reduced, and the beam pattern becomes smaller. Both of these effects result in increasing the LPI of the remote.

Possible options for the remote antenna include a non-tracking fan beam type, a directive tracking antenna, and a multi-beam phased-array nulling type. The fan beam would be oriented such that the wide part of the beam pattern is aligned with the orbital arc of the satellite such that the antenna need not track the movement of the satellite one set up. The directive antenna could have a very small beamwidth

and be either mechanically or electronically steerable. In this case, the antenna would have to track the satellite's movement across the sky. In both of these antenna options two antennas might be required to prevent outages during handover from one satellite to another. The final option involves a phased-array antenna capable of producing multiple beams and placing nulls at desired locations.

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